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ASSESSING HEAVY METAL CONTAMINATION IN SELECTED FARM VEGETABLES AND SOILS

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ABSTRACT

Purpose: The research sought to evaluate the heavy metal concentrations in frequently eaten vegetables within the Sunyani Municipality.

Design/Methodology/Approach: Carrots, cabbage, lettuce, and garden eggs sourced from various farms have been analysed about the soils in which they are cultivated, utilising the absorption atomic spectrometer (AAS) technology.

Findings: The amounts of iron (Fe), nickel (Ni), lead (Pb), arsenic (As), cadmium (Cd), zinc (Zn), and copper (Cu) in cultivation soil and vegetal samples significantly exceeded permitted limits established by WHO/FAO. The accumulation levels of metals recorded in the current study for the soil samples are ranked in descending order as follows: Fe>Mn>Cu>Zn>Pb>As>Cd>Ni. A similar pattern is noted in the diminishing concentrations of metals recorded for the vegetable samples.

Research Limitation: The study is limited to selected farms within the Sunyani township, and findings may not reflect the full extent of contamination across other regions in Ghana. Expanding to different climatic or agricultural regions would improve generalisability.

Practical Implication: The study may help public health authorities establish regular testing of market produce, ensuring compliance with WHO/FAO permissible limits for heavy metals.

Social Implication: The research raises awareness of the long-term consequences of consuming contaminated food, promoting advocacy for food safety and environmental stewardship at the community level.

Originality/ Value: The study's inclusion of soil and vegetable analysis offers a comprehensive understanding of contamination pathways.

Keywords*: Bioaccumulation. heavy metals. soils. toxicity. vegetables*

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INTRODUCTION

Vegetables are critical elements of a hale and hearty human diet, providing essential nutrients like folic acid, vitamin C, and dietary fibre, alongside essential trace elements such as niacin and thiamine. These micronutrients contribute to human nutrition and play antioxidant roles (Awasthi *et al.*, 2022). Nonetheless, food quality is progressively undermined by environmental pollution, especially from heavy metals like lead (Pb), cadmium (Cd), and mercury (Hg). Prioritising the safety of food from heavy metal pollution is essential for public health, as highlighted by the United Nations Sustainable Development Goal (SDG) 3, which talks about good health and well-being of living organisms, and SDG 12, which advocates for accountable cultivation, manufacturing and ingesting of food products (UN, 2015; Yang *et al.*, 2024).

Heavy metals (trace elements) persist in agricultural environments through soil contamination, atmospheric deposition, and anthropogenic activities like industrial emissions and fertiliser use (Aransiola *et al.*, 2023). In several cases, trace elements accrue in agricultural lands and are assimilated by plants, presenting considerable health hazards to consumers (Frontiers, 2023). Trace elements or heavy metals could be harmful owing to their prolonged organic half-lives, non-decaying characteristics, and propensity to build in many bodily tissues (Monu *et al*., 2008; Heidarieh *et al*., 2013). Contamination of consumable crops frequently remains unnoticed, as visible indicators of contamination are typically absent (Mohammadi *et al*., 2019). Prolonged ingestion of vegetables cultivated in contaminated soil may result in the buildup of trace elements or heavy metals in human organs, including the liver and kidneys, hence contributing to cardiovascular, renal, and neurological problems (Järup, 2003; Mohanty *et al*., 2024).

The health risk to humans from vegetable consumption is contingent upon the volume of vegetables ingested and the individual's body weight. Chronic consumption of heavy metals at low molarity adversely affects human health, with the harmful effects becoming evident after long-term exposure (Liu *et al*., 2005; Huang *et al*., 2007; Bortey-Sam *et al*., 2015).

Heavy metals, by description, are trace elements with a specific density of over 5 g/cm3 that have a destructive influence on the biosphere and its occupants (Järup, 2003). They are undoubtedly significant elements for plants and humans, even in minimal quantities. Certain micronutrient elements can be hazardous to both animals and plants at elevated amounts. Examples include copper (Cu), chromium (Cr), fluorine (F), molybdenum (Mo), nickel (Ni), selenium (Se), and zinc (Zn). Other trace

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elements, including arsenic (As), cadmium (Cd), mercury (Hg), and lead (Pb), are harmful even in minimal amounts (Divrikli *et al*., 2006). Because of their perseverance and non-decayability, heavy metals cannot be eliminated through conventional cropping methods nor readily leached by rainfall (Khadeeja *et al*., 2013). There could be leaching or transferred from agricultural lands to groundwater or absorbed by vegetation, including farm crops.

Understanding element and vegetation exchanges is crucial for environmental protection (Divrikli *et al*., 2006). There has been growing attention towards assessing heavy metal concentrations in publicly supplied food. Nonetheless, their molarity in bioavailable form is not necessarily proportionate to the overall metal content (Opaluwa *et al*., 2012; Nwachukwu *et al*., 2010). Soil, the paramount element of the biosphere, is persistently devalued, misapplied, and exploited (Gokulakrishnan *et al*., 2010). The rapid escalation of soil contamination has become a widespread concern in industrialised and urbanised regions globally (Huang *et al*., 2019).

Soil is the primary repository for environmental contaminants, collecting detrimental compounds that jeopardise ecosystem equilibrium (Shokoohi *et al*., 2009). Most vegetation's continuous growth and development, including all domestic and wildlife, depends on the soil as a growth medium. The presence of harmful compounds or pollutants in soil undermines life support functions. The release of untreated industrial and domestic effluents introduces organic and inorganic pollutants into the soil (Shetty & Rajkumar, 2009; Gowd *et al*., 2010; Golly *et al.*, 2016). Heavy metal contamination presents considerable hazards to human health and plant development, even at micronutrient concentrations (Murugesan *et al*., 2008; Singh *et al*., 2020).

The Sunyani Municipality in Ghana is undergoing swift urbanisation and intensified agriculture, heightening the risk of heavy metal soil contamination. Prior research indicates that crops cultivated in these regions could absorb trace elements from polluted soil or air (Yang *et al*., 2024). Nevertheless, there is a paucity of evidence regarding the extent of heavy metal pollution in soils and plants in the Sunyani area. This study seeks to address the disparity by assessing the amounts of certain heavy metals in soil and vegetables concerning FAO/WHO safety criteria for food items. This work is crucial for advancing sustainable agricultural practices and ensuring food safety, as it offers evidence-based suggestions for reducing hazards linked to heavy metal intake via vegetables. The study will contribute to SDG 15 - Life on Land - by identifying pollution levels, encouraging healthy ecosystems and

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conserving terrestrial resources (UN, 2015). This research will guide policymakers, farmers, and the local community, enhancing agricultural practices and communal well-being.

LITERATURE REVIEW

The increasing contamination of agricultural produce by heavy metals has emerged as a global challenge, significantly impacting food safety and public health. Vegetables, a crucial component of the human diet, often absorb these contaminants from soils, leading to bioaccumulation. These metals, including lead (Pb), cadmium (Cd), and arsenic (As), pose severe risks to human health when present in concentrations exceeding permissible limits (Awasthi *et al.*, 2022). Heavy metal contamination occurs through natural geological processes, anthropogenic activities like industrial emissions, and agrochemicals, thereby infiltrating the food chain and disrupting ecological balance (Aransiola *et al.*, 2023; Mohammadi *et al*., 2019).

Heavy Metals in Agricultural Soils

Heavy metals, defined by their density exceeding 5 g/cm³, are naturally occurring elements essential in trace amounts but toxic at higher concentrations (Järup, 2003). Soil serves as a reservoir for these metals, where industrial runoff, mining activities, and excessive use of fertilisers contribute to contamination (Gokulakrishnan *et al.*, 2010; Huang *et al.*, 2019). Studies reveal alarming levels of heavy metals in urban soils, exacerbating risks of leaching into crops. For instance, cadmium and lead concentrations frequently exceed permissible thresholds, threatening crop productivity and human health (Nwachukwu *et al.*, 2010; Singh *et al.*, 2020). The Sunyani Municipality, characterised by rapid urbanisation and intensified agricultural practices, exemplifies the intersection of these challenges. Research indicates substantial contamination of soils with heavy metals like iron (Fe) and zinc (Zn), which can accumulate to toxic levels in crops (Yang *et al.*, 2024). This phenomenon necessitates comprehensive soil testing and remediation strategies to mitigate risks.

Bioaccumulation in Vegetables

Vegetables grown in contaminated soils often exhibit bioaccumulation, a process influenced by soil composition, crop type, and environmental factors (Divrikli *et al.*, 2006). Bioaccumulation of heavy metals in vegetables is a critical concern, as these crops serve as dietary staples worldwide, particularly in low- and middle-income countries. The phenomenon occurs when plants absorb heavy metals from contaminated soils, water, and atmospheric deposits. Factors influencing bioaccumulation include the type of metal, soil properties (e.g., pH, organic matter content), and the specific physiological traits of

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the vegetable. Leafy vegetables such as lettuce and cabbage are particularly prone to higher accumulation due to their larger surface areas, extensive root systems, high transpiration rates and more direct exposure to contaminants during irrigation or atmospheric deposition (Lente *et al.*, 2012; Sharma *et al.*, 2018). The literature revealed elevated levels of metals, including arsenic and cadmium, in lettuce and garden eggs, often surpassing WHO/FAO thresholds (Mohammadi *et al.*, 2019). Moreover, bioaccumulation varies among metals; cadmium, for instance, exhibits high soil-to-plant transfer rates, leading to disproportionate levels in crops relative to soil concentrations (Sharma *et al*., 2018). This was evident in studies from Ghana, where cadmium levels in vegetables cultivated near industrial sites significantly exceeded safe limits (Bortey-Sam *et al*., 2015).

Health Implications of Heavy Metal Exposure

Prolonged consumption of heavy metal-contaminated vegetables is linked to a variety of health issues, ranging from gastrointestinal distress to chronic diseases such as cancer and neurological disorders (Järup, 2003). Cadmium and lead are particularly concerning due to their carcinogenic potential and ability to cause kidney damage and cognitive impairments (Suruchi & Pankaj, 2011). Studies have shown that even low levels of these metals, when consumed over time, accumulate in the human body, leading to systemic toxicity (Mohanty *et al*., 2024). Research by Muchuweti *et al.* (2006), indicated that vegetables irrigated with wastewater exhibited lead levels tenfold higher than permissible limits. This underscores the urgent need for agricultural practices and consumer awareness interventions.

Regulatory Frameworks and Interventions

The WHO and FAO establish permissible limits for heavy metals in soils and crops, offering guidelines critical for safeguarding public health. For instance, the maximum allowable levels for cadmium and lead in vegetables are 0.2 mg/kg and 0.3 mg/kg, respectively (FAO/WHO, 2011). However, adherence to these standards remains inconsistent, particularly in developing regions with limited regulatory oversight. For effective interventions, there is a need for a multifaceted approach to mitigating heavy metal menace. The approach should involve soil remediation using phytoremediation and biochar application, which can reduce bioavailable heavy metals in soils (Aransiola *et al.*, 2023). Secondly, there should be policy enforcement through strengthened regulatory frameworks and routine monitoring essential for compliance with safety standards (Singh *et al*., 2020). Thirdly, public awareness should be increased by educating farmers and consumers alike on the risks associated with contaminated produce to foster safer practices (Bortey-Sam *et al*., 2015).

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Continuous Research

Despite advancements in understanding heavy metal contamination, significant gaps remain—the variability in bioaccumulation among different crops and environmental conditions warrants further investigation. Additionally, long-term studies assessing the chronic health impacts of low-level heavy metal exposure are crucial for informing public health policies (Mohammadi *et al.*, 2019). Localised research is also needed to address regional variations in contamination sources and pathways. Expanding such studies to include diverse agricultural regions will enhance the generalizability of findings and support targeted interventions.

METHODOLOGY

Materials

Soil auger, polythene bags sterilised with 70% ethanol, stainless steel knives, and distilled water were used for sample collection. Nitric Acid (HNO_3), Hydrochloric Acid (HCl) and Perchloric Acid ($HClO_4$) are used for digesting soil and vegetable samples to extract heavy metals (Singh & Praharaj, 2017; Guo *et al.*, 2006) were of analytical grade.

Description of the study area

Sunyani serves as both a regional hub and a commercial centre of the Bono Region. The 2010 Population and Housing Census revealed that Sunyani had a population of approximately 123,224 people at the time, representing a mix of urban and rural communities. The population of Sunyani has grown significantly over the years, with the latest figures from the 2021 census placing the population of the Sunyani Municipal District at 193,595, reflecting a growing urban character and increased migration to the area (GSS, 2021).

The residents of Sunyani predominantly belong to the Bono ethnic group. The region also accommodates other ethnic minorities from different parts of Ghana, reflecting the country's diverse and multicultural landscape. These ethnic dynamics contribute to Sunyani's development and socio-economic growth by creating a pool of skilled and unskilled labour (Bono Regional Report, 2021). The growing urbanisation and agricultural activities in Sunyani, alongside its population growth, have made the area a focus for both environmental studies and policy planning, such as in research on agricultural contamination, which aligns with your study's objectives (GSS, 2021; BRCC, 2021). Two (2) main study locations were chosen for the study, which comprised Asufu and Waterloo (on the Sunyani Technical University campus).

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Sample Collection

Two vegetable-growing farms within Sunyani were selected purposively, ensuring that both an urban (Waterloo - Sunyani Technical University campus) and peri-rural (Asufufu) farms were included. A total of five farms (four from 'Waterloo' and one from Asufufu) were chosen, focusing on cultivating vegetables such as lettuce, cabbage, and garden eggs, which are known to absorb higher concentrations of heavy metals from the ground. Respective farmland and vegetal samples were collected from each farm plot for analysis.

Vegetable Samples

The consumable portions of the chosen vegetables were gathered at optimal harvest stages. Three distinct portions were collected for each crop, and a composite sample was created by amalgamating sections from the three. The samples were rinsed with deionized water to eradicate dirt and air-dried before analysis. The vegetable samples were excised from all the plants using a stainless-steel knife and labelled. The vegetal samples were stored in sealable polypropylene bags and appropriately labelled.

Soil Samples

Farmlands were sampled from the topsoil (0-20 cm layer) using a stainless-steel auger to prevent cross-contamination. At each sampling point, three sub-samples were taken from different parts of the farm, and these were combined to form a composite sample. The samples were packaged in sanitised and labelled sealable polyethene bags and conveyed to the research lab for examination.

Methods

Soil treatment for AAS examination

Farmland samples were air-dried for 48 hours in a hood chamber and thereafter cleansed of stones and plant residues after being powdered to a particle size of 2mm. Similar quantities of the dried samples from identical depths were meticulously combined to provide a representative composite for each sampling site. The mixture was sufficiently mixed by swirling in a spherical manner, alternating movements, and periodically inverting the material (SESD Operating Procedure Soil Sampling, 2011). The filtered and composite farm land samples were preserved in sealable polyethene bags for subsequent examination.

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Treatment of Vegetable Samples for AAS Analysis

The vegetal samples were meticulously rinsed with water and sectioned using a stainless-steel knife. Subsequently, they were freeze-dried at 17 17˚C under a vacuum of 6.110 bar. Following 48 hours of drying in the freeze dryer (WM-FDG0.6, Zhengzhou Wenming Machinery Co., Henan Province, China), the vegetal samples were pulverised using a stainless-steel blade blender (Vitamix Ascent A3500, Tita-Mix Cooperation, Ohio, USA), and various heavy metal assays were conducted on them.

Digestion of Soil Samples

The soil samples were measured into labelled 100ml polytetrafluoroethylene (PTFE) Teflon bombs (YHR-25, Shanghai Yuanhuai Intelligent Technology Co., Shanghai, China) that had been acid-washed beforehand. Each sample received 6 ml and 3 ml of concentrated nitric acid (HNO3, 65%) and hydrochloric acid (HCl, 35%), respectively, as well as 0.25 ml of hydrogen peroxide (H2O2, 30%) in a hood chamber. The samples were thereafter placed on the microwave carousel. The vessel caps were firmly fastened with a wrench. The entire assembly was subjected to microwave irradiation for 26 minutes utilising the Milestone microwave lab station (MLS-1200 MEGA, Ethos 900, USA) (Musa & Decker, 2016).

Acid digestion of vegetable

A duplicate of 0.2 g sample weight of each vegetable sample was put in a digestion flask and subjected to 10 ml and 5 ml of concentrated HNO3 and H2SO4 treatment, respectively. 10 ml of HNO3 and 5 ml of H2SO4 were combined in an empty digestion flask for a blank sample (Sahito *et al*., 2002). The respective flasks were put on a heating source: an electric hot plate (HP 220, UTEC Products Inc., Albany, NY, USA) with a temperature of 80-90 °C for 2 hours, increased to 150 °C, to induce boiling. 3-5 ml of concentrated HNO3 and H2SO4 were incrementally added to the digestion sample until a transparent solution was achieved.

The mixture was cooled and then filtered using Whatman No. 42 filter paper and a Millipore filter paper having a pore size of fewer than 0.45 micrometres. The solution was quantitatively transferred to a 50 ml volumetric flask and diluted to the mark with deionised water. The filtered 50 ml solution was put into an acid-washed polyethene sample container labelled for analysis. An atomic absorption spectrophotometer (AAS), model AAS-6300 from Shimadzu, was used to determine the content of heavy metals in the vegetal samples. Results were presented as mg/kg of dry weight of the respective samples.

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Heavy metals Assay

After digestion, the Teflon bombs positioned on the microwave carousel were cooled in a water bath to alleviate internal pressure and facilitate the re-stabilization of volatilised substances (Smith *et al*., 2010). The digests from 2.4.3 and 2.4.4 with their respective blank solutions were assayed for their trace element or heavy metal contamination.

The Atomic Absorption Spectrometer (AAS) (AAS-6300, Shanghai) was calibrated after every three analyses, utilising air-acetylene gas to produce free atoms from elements such as Zinc, Lead, and Cadmium (Jones & Chen, 2015). Blanks were atomised, and subsequently, the standards and calibration graphs were displayed to illustrate the response from the ASS.

The concentrations were subsequently determined using absorbance measurements under the Beer-Lambert equation (Lee & Park, 2013). Responses to the standard were utilised to determine the machine's precise performance and the trace elements' exact concentration values. The machine underwent calibration following every three analyses.

A hollow cathode lamp produced the illumination at a wavelength specific to each analysis. Subsequently, each analysis was atomised utilising an atomiser to generate free atoms from the samples. Air-acetylene gas served as the energy source for generating free atoms of the elements Zinc (Zn), Lead (Pb), Copper (Cu), Nickel (Ni), Iron (Fe), Cadmium (Cd), Arsenic (As), and Manganese (Mn). The sample was injected into the flame as an aerosol, and the burner was positioned to block the optical path, allowing the light beam to pass through the flame and be absorbed.

A monochromator then separated the analytical and non-analytical wavelengths emitted by the hollow cathode lamp, separating the light into its parts. The sensitive light detector subsequently quantifies the light, transforming the response into analytical measurements.

Ensuring and Controlling Quality

Rigorous quality assurance and quality control (QA/QC) protocols were implemented during the study to guarantee the trustworthiness of the data, a customary approach in heavy metal analysis (Jorhem & Sundström, 1993; Salim *et al*., 2016). All reagents and chemicals employed were of superior purity. Suitable protocols and safeguards were established to ensure the accuracy and precision of the results (Mohammed *et al*., 2014). Deionized water was utilized regularly throughout the investigation to

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prevent contamination. Glassware and high-density polyethylene (HDPE) bottles were cleaned with 20% nitric acid (HNO_3), utilizing analytical grade chemicals (Abdu *et al*., 2011). Metal standards were established from stock solutions to calibrate the Atomic Absorption Spectrophotometer (AAS) to ensure the instrument's validity (Salim *et al*., 2016).

Analyses, including reagent blanks and standards, were replicated after every ten sample measurements to ensure the precision and accuracy of the analytical data (Mohammed *et al*., 2014). The recovery rates for all elements varied between 80% and 110%, signifying dependable analytical performance (Salim *et al*., 2016).

Analysis of data

The analysis was run twice to reduce or eliminate the likelihood of mistakes. The averages and standard deviations of the micronutrient and heavy metal concentrations in the different samples were computed using the MS Excel program. T-tests were used for comparison.

RESULTS AND DISCUSSION

The study focused on the accumulation of heavy metals (arsenic, cadmium, lead, nickel) and micronutrients (iron, zinc, manganese, copper) in the vegetables and soil samples. The accumulation levels based on the atomic absorption spectrometric determination for heavy metals (As, Cd, Pb & Ni) and micronutrients (Fe, Zn, Mn & Cu) are presented in Table 1-3. There were significant differences in the accumulation levels of the vegetable and soil samples.

Arsenic (As)

From Table 1, the arsenic (As) concentrations in the vegetable samples ranged from 0.84 mg/kg (STU garden eggs) to 1.14 mg/kg (STU lettuce), which is significantly above the recommended safety limits 0.1 mg/kg maximum permissible limit of arsenic in vegetables (FAO/WHO, 2011). This poses serious public health concerns, as arsenic is highly toxic even at low concentrations, leading to skin lesions, cancer, and other chronic diseases (Awasthi *et al.*, 2022). For the soil samples, the arsenic levels ranged from 3.96 mg/kg (STU lettuce) to 8.78 mg/kg (STU carrot). These levels of arsenic in agricultural farmland are lower than the FAO permissible level of arsenic in agricultural soil at 20 mg/kg, but they still raise a cause for concern. Though within the soil allowable limits, the high vegetable concentration

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indicates strong plant uptake (Mohammadi *et al.*, 2019), which raises the need for further investigation of soil-to-plant transfer mechanisms (Sharma *et al.*, 2018).

Cadmium (Cd)

Cadmium (Cd) concentrations in the vegetables ranged from 0.97 mg/kg (STU garden eggs) to 2.10 mg/kg (STU lettuce) (Table 1). The results indicate that cadmium concentration in the four vegetables exceeds the permissible limit of 0.2 mg/kg) by more than tenfold in some samples (FAO/WHO, 2011). Cadmium concentrations in soils ranged from 0.57 mg/kg (STU lettuce) to 1.68 mg/kg (STU cabbage), within acceptable soil contamination limits.

Despite low soil concentrations, the unequal buildup of cadmium in vegetables indicates high cadmium bioavailability in the farming area. The lead levels in vegetables ranged from 0.55 mg/kg (STU carrot) to 0.85 mg/kg (STU garden eggs), all exceeding permissible levels. The maximum allowable limit for lead in vegetables is 0.3 mg/kg (FAO/WHO, 2011).

The current study reveals a similar cadmium accumulation level as reported in the literature. Lente *et al*. (2012) conducted a study that revealed cadmium levels exceeding the detection limit in vegetables cultivated in long-term agricultural settings in Accra. Similarly, Odai *et al*. (2008) found higher cadmium contents ranging from 0.68 to 1.78 mg kg-1 in vegetables grown on Kumasi rubbish dumping sites.

Studies conducted in Varanasi, Harare, and Addis Abeba found cadmium concentrations that were one to five times higher than the MRL, according to previous studies (Mapanda *et al*., 2007; Sharma *et al*., 2018; Weldegebriel *et al*. 2012). In their study of native vegetables (Tsunga leaves) irrigated with wastewater in Harare, Muchuweti *et al*. (2006) found a cadmium concentration of 3.68 mg kg-1. This concentration is 18 times higher than what is allowed by EU rules.

Cadmium is increasingly recognised as a significant health risk in agriculture because to its association with kidney and bone damage, as well as its potential carcinogenic properties (Suruchi & Pankaj, 2011). High cadmium exposure is associated with kidney damage and skeletal deformities (Järup, 2003). This poses a serious risk to consumers, especially those who regularly consume these vegetables.

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Lead (Pb)

Chronic lead (Pb) exposure can cause cognitive impairments and other significant health difficulties; lead is especially hazardous to children and has toxic effects on various organs, including the kidneys, liver, lungs, and spleen, which can lead to biochemical anomalies (Mohammadi *et al*., 2019). For the soil samples, the lead concentrations, as reported in Table 1, ranged from 8.59 mg/kg (STU lettuce) to 12.77 mg/kg (STU carrot), all below the 50 mg/kg limit for agricultural soils. However, the high uptake in vegetables poses a threat, indicating that even moderate soil contamination can lead to hazardous vegetable contamination.

Nickel (Ni)

Nickel (Ni) concentrations in vegetables were below the recommended limit for nickel in vegetables is 1.5 mg/kg (EFSA, 2013), ranging from 0.70 mg/kg (Asufufu cabbage) to 1.17 mg/kg (STU lettuce). These levels are within safe limits, but prolonged consumption could lead to allergic reactions or respiratory issues (Divrikli *et al.*, 2006). Nickel concentrations in the soil samples ranged from 0.42 mg/kg (STU lettuce) to 1.41 mg/kg (STU garden eggs), within the safe limits for soil contamination. Soil samples from farms showed a nickel (Ni) concentration of 0.42–1.68 mg/kg, whereas vegetable samples showed a value of 0.58–0.86 mg/kg.

According to WHO/FAO (2007), 0.10 mg/kg is acceptable. Although the body needs nickel in tiny levels, it is mostly found in the pancreas and is essential for insulin manufacturing. Khan *et al*. (2008) found that liver illness results from a deficiency. It is possible that the heavy metals entered the plants by two pathways: adsorption, which means that the metals or materials stuck to the surface, or absorption, which means that trace metals entered the plant's interior structure.

The absorption of heavy metals by plants is a continuous process that reaches its peak around the end of the vegetative phase (Krstic *et al*., 2007; Stankovic, 2006; Milan Knezevic *et al*., 2009). Bioaccumulation is the process of magnifying toxic heavy metals within living organisms. According to Suciu *et al*. (2008), when these metals settle into soil and plants, they hurt the soil's physicochemical characteristics and plant processes.

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Table 1: Mean±SD of Heavy Metal concentration (mg/kg) in vegetable and soil samples from the various farms.

Metal	Source	Veg.	Soil	Permissible Maximum Values (mg/kg)
	Asufufu cabbage	0.95±0.06^{ab}	7.24 ±7.02^{b}	
	STU carrot	1.07±0.09^{bc}	8.78±0.78^{c}	
As	STU cabbage	0.97±0.04^{ab}	7.83±0.76^{bc}	**0.0l (FAO/WHO, 2011)**
	STU garden eggs	0.84±0.06^{a}	5.13±0.33^{a}	
	STU lettuce	1.14±0.02^{c}	3.96±0.31^{a}	
	Asufufu cabbage	1.35±0.16^{a}	1.40±0.19^{b}	
	STU carrot	1.50±0.39^{ab}	1.35±0.07^{b}	
Cd	STU cabbage	1.52±0.16^{ab}	1.68±0.14^{b}	**0.2 (FAO/WHO, 2011)**
	STU garden eggs	0.97±0.05^{a}	1.67±0.23^{b}	
	STU lettuce	2.10±0.30^{b}	0.57±0.08^{a}	
	Asufufu cabbage	0.73±0.03^{c}	11.51±0.49^{b}	
	STU carrot	0.55±0.02^{a}	12.77±0.22^{c}	
Pb	STU cabbage	0.67±0.05^{bc}	8.95±0.60^{a}	**0.3 (Mensah *et al*., 2009)**
	STU garden eggs	0.85±0.02^{d}	10.78±0.48^{b}	
	STU lettuce	0.66±0.02^{b}	8.59±0.79^{a}	
	Asufufu cabbage	0.70±0.10^{a}	0.97±0.06^{b}	
	STU carrot	0.85±0.15^{ab}	1.37±0.20^{c}	
Ni	STU cabbage	1.04±0.11^{ab}	0.85±0.11b	**0.1 (FAO/WHO, 2007)**
	STU garden eggs	0.71±0.07^{a}	1.41±0.26^{c}	
	STU lettuce	1.17±0.20^{b}	0.42±0.06^{a}	

Means with different superscripts down the column are significantly different for each heavy metal.

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Table 2: Mean±SD of micronutrient concentration (mg/kg) in vegetable and soil samples from the various farms

Metal	Source	Veg.	Soil	Permissible Maximum Values (mg/kg)
	Asufufu cabbage	979.53±11.61[d]	17,037.33±512.26[c]	
	STU carrot	2,192.67±25.54[f]	2,240.40±5.90[a]	
Fe	STU cabbage	122.20±8.68[a]	2,333.60±20.50[a]	450 (FAO/WHO, 2007)
	STU garden eggs	351.53±11.60[b]	6,533.33±22.03[b]	
	STU lettuce	509.80±14.30[c]	2,332.80±16.71[a]	
	Asufufu cabbage	187.20±15.08[b]	36.11±4.63[a]	
	STU carrot	74.07±9.66[a]	113.37±4.85[d]	
Zn	STU cabbage	66.42±8.02[a]	78.17±11.37[c]	60 (FAO/WHO, 2007)
	STU garden eggs	49.81±6.77[a]	61.25±6.66[b]	
	STU lettuce	71.83±4.98[a]	108.67±1.19[d]	
	Asufufu cabbage	74.93±0.75[c]	399.50±2.33[d]	
	STU carrot	49.72±3.24[b]	230.60±1.41[c]	
Mn	STU cabbage	52.89±1.45[b]	228.63±7.48[c]	50 (FAO/WHO, 2007)
	STU garden eggs	16.55±2.49[a]	190.60±3.72[b]	
	STU lettuce	192.07±2.65[d]	123.93±1.17[a]	
	Asufufu cabbage	164.30±10.18[c]	82.85±1.98[a]	
	STU carrot	612.80±11.29[d]	186.80±4.33[c]	
Cu	STU cabbage	88.58±3.05[b]	82.29±6.45[a]	73.3 (FAO/WHO, 2007)
	STU garden eggs	59.30±13.63[a]	183.63±4.56[c]	
	STU lettuce	51.00±2.21[a]	94.22±0.68[b]	

Means with different superscripts down the column are significantly different for each micronutrient.

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Iron (Fe)

Vegetable iron (Fe) contents varied from 122.20 mg/kg for STU cabbage to 2192.67 mg/kg for STU carrots. There was a very high concentration of iron in the soil from the Asufufu cabbage fields (17037.33 mg/kg) (Table 2), which could lead to much buildup in some veggies. There may not be a hard and fast rule about how much iron a person should consume, but too much of it can lead to tissue damage and oxidative stress (Awasthi *et al*., 2022).

The extraordinarily high iron levels in the STU carrots' crops and soil suggest that the plant may be able to bio-absorb iron from the soil. Vegetable samples with increased Fe contents clearly demonstrate soil-to-plant tissue iron absorption disparities. For vegetable samples, the detected changes are as little as tenth, twenty-five, and twenty-five percent of the initial amounts of Fe in the soils, respectively.

The elevated amounts of Fe in the soil samples suggest that there may be a significant anthropogenic source of Fe, which allows it to permeate deeper into the soil rather than staying on top. The low levels of iron in the vegetable samples, even though it is abundant in the soils, could be due to two things: (i) the plant tissues not absorbing enough iron, and (ii) the possibility of iron leaching from the soil surface and its subsequent flow during rainfall. Iron activates numerous respiratory enzymes in plants and is essential for chlorophyll synthesis. Respiratory issues, such as chronic bronchitis and trouble breathing, can develop from prolonged contact with iron dust. The iron level in the vegetable samples and the soils where they are grown is higher than the 450 mg kg^{-1} limit set by the WHO/FAO (WHO/FAO, 2007).

Zinc (Zn)

Zinc (Zn) concentrations ranged from 49.81 mg/kg (STU garden eggs) to 187.20 mg/kg (Asufufu cabbage) (Table 2). The zinc concentrations in Asufufu cabbage exceeded the recommended limits, indicating potential health risks, including nausea and immune system dysfunction (Sharma *et al.*, 2018). The recommended upper limit for zinc in vegetables is 100 mg/kg. Soil zinc levels ranged from 36.11 mg/kg (Asufufu cabbage) to 113.37 mg/kg (STU carrot) (Table 2). The Zn concentration levels of soil in this study exceed the permissible limits of 60 mg/kg (WHO/FAO, 2007). This suggests differential uptake rates for zinc depending on the vegetable and soil type. Concentrations of Zn in contaminated soils often surpass the levels necessary for nutrition and may induce phytotoxicity. Elevated Zn concentrations in soil impede certain plants' metabolic processes, leading to stunted

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development and inducing senescence. Zinc poisoning in plants can inhibit the growth of both roots and shoots (Choi *et al*., 1996). Zinc is essential for healthy immune system function and is a necessary and non-toxic element for human consumption. Human health may be more negatively impacted by a zinc deficiency in the diet than by excess zinc consumption. Zinc is recommended at 15 mg/day for males and 12 mg/day for women by the Agency for Toxic Substances and Disease Registry. However, it is important to note that vegetables with high zinc levels can cause nausea, vomiting, kidney problems, and cramps (ATSDR, 2007).

Manganese (Mn)

Manganese (Mn) concentrations in vegetables ranged from 16.55 mg/kg (STU garden eggs) to 192.07 mg/kg (STU lettuce) (Table 2). The present study revealed that the manganese concentrations in the four vegetables were above the WHO / FAO stipulated limit of 50 mg kg-1 (WHO / FAO 2007). The soil manganese levels were highest in Asufufu cabbage soils (399.50 mg/kg) and lowest in (123.93 mg/kg) (Table 2), indicating substantial bioavailability of manganese in the soils (Mohammadi *et al.*, 2019).

Typically, manganese contents are higher in soil samples than in vegetable tissue samples. The increased concentrations of Mn in the vegetable samples support the substantial absorption of Mn by the plant tissues from the soil and other natural sources in their environment. Manganese is a necessary trace element for the growth of plants and animals. The absence of this factor leads to considerable structural and reproductive irregularities in mammals.

A high manganese (Mn) concentration adversely affects humans' pulmonary and cerebral systems (Järup, 2003). Excess manganese (Mn) has been shown to inhibit chlorophyll synthesis by disrupting the iron (Fe) pathway (Clarimont *et al*., 1986). Manganese poisoning is a significant concern compared to other micronutrient toxicities. It is generally associated with soils having a pH of 5.5 or lower but can also occur when the soil pH is below 6.0. Symptoms may include chlorosis and necrotic lesions on mature leaves, dark brown or red necrotic patches, and the accumulation of small particles of MnO_2 in the epidermis.

Copper (Cu)

Copper contents in vegetables varied from 51.00 mg/kg in STU lettuce to 612.80 mg/kg in STU carrots (Table 2). The copper concentrations in the four vegetable samples were markedly beyond the safety

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limit of 40 mg/kg (WHO/FAO 2007). Soil copper concentrations varied from 82.85 mg/kg (Asufufu cabbage) to 186.80 mg/kg (STU carrot) (Table 2), demonstrating a notable presence of copper in the soil. This indicates that the copper concentration in the different veggies is hazardous for intake. Excessive copper consumption may result in gastrointestinal upset and hepatic impairment (Yang *et al*., 2024).

According to a study by Lente *et al*. (2012) in Ghana, Cu values in vegetables from a perpetual effluent-watered urban agricultural site in Accra were below 10 mg kg-1, less than the concentration levels observed in this study. Copper is a vital trace micronutrient for humans. An overdose of copper can result in detrimental consequences on one's wellbeing (Rahman *et al*., 2014). Excessive copper can result in immediate gastrointestinal pain and hepatic impairment (Rahman *et al*., 2014). Comparable research undertaken in Varanasi by Singh *et al*. (2010) found increased levels of Cu.

Table 3: Comparison of Mean±SD of (a) Heavy metal and (b) Micronutrient concentration (mg/kg) in veg. & soil samples from the various farms

(a)

Metal	**Source**	**Veg.**	**Soil**
As	Asufufu	0.95±0.06^{a}	7.24 ±7.02a
	STU	1.01±0.34^{a}A	6.43±0.56^{b}B
Cd	Asufufu	1.35±0.16^{a}A	1.40±0.19^{a}A
	STU	1.52±0.17^{b}A	1.31±0.23^{a}B
Pb	Asufufu	0.73±0.03^{a}	11.51±0.49^{b}
	STU	0.68±03^{a}B	10.27±0.15^{a}A
Ni	Asufufu	0.70±0.10^{a}B	0.97±0.06^{a}A
	STU	0.94±0.12^{b}A	0.95±0.56^{a}A

(b)

Nutrient	**Source**	**Veg**	**Soil**
Fe	Asufufu	979.53±11.61^{a}B	17,037.33±512.26^{a}A
	STU	794.05±5.54^{b}B	3,359.93±12.76^{b}A
Zn	Asufufu	187.20±15.08^{a}A	36.11±4.63^{b}B
	STU	65.53±4.85^{b}B	90.37±9.66^{a}A
Mn	Asufufu	74.93±0.75^{a}B	399.50±2.33^{a}A
	STU	77.81±3.24^{a}B	193.44±1.41^{a}A
Cu	Asufufu	164.30±10.18^{b}A	82.85±1.98^{b}B
	STU	202.92±9.29^{a}A	136.74±4.33^{a}B

Means with different superscripts down the column are significantly different, and different uppercase letters in a row are significantly different for each heavy metal and micronutrient.

Table 3 shows significant differences between the heavy metal accumulation levels in the vegetable samples. As expected, the soil concentrations for heavy metals like arsenic, cadmium, and lead were generally higher than the corresponding vegetable concentrations. For example, STU lettuce showed

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the highest accumulation levels of cadmium and arsenic (Table 3a), indicating it absorbs higher levels of these metals than vegetables like garden eggs and carrots. However, vegetables like STU lettuce showed disproportionately high levels of cadmium and lead relative to the soil, indicating efficient metal uptake. This highlights the need for specific attention to crops like lettuce, which may pose higher risks of heavy metal exposure.

Also, the soil samples exhibited variability in their micronutrient accumulation levels. Asufufu cabbage soils had extremely high levels of iron and zinc, while STU lettuce soils had lower heavy metal concentrations (Table 3b). This suggests varying soil contamination levels between farms, which could be attributed to factors like irrigation methods or fertiliser use.

The extremely high concentrations of iron and zinc in Asufufu cabbage relative to soil indicate a strong potential for bioaccumulation. These findings emphasise the significance of ongoing monitoring and intervention, especially for crops with strong tendencies to accumulate trace metals.

CONCLUSION

This research aimed to assess the concentrations of heavy metals in commonly consumed vegetables in the Sunyani township. The carrots, cabbage, lettuce, and garden eggs obtained from various farms have been analysed for their heavy metal levels to the soils in which they were cultivated, utilising Absorption Atomic Spectrometer (AAS) technology. The concentrations of iron (Fe), nickel (Ni), lead (Pb), arsenic (As), cadmium (Cd), lead (Ph), zinc (Zn), and copper (Cu) in soil and vegetable samples surpass the permissible thresholds set by WHO/FAO for soils and plants.

The soil samples exhibit metal concentrations ranked in descending order: Fe, Mn, Cu, Zn, Pd, As, Cd, and Ni. A similar pattern was observed in the metal concentrations within the vegetable samples. This shows that the vegetal tissues absorb and retain metals more, and plants have additional non-anthropogenic heavy metal pollution. This study found that cabbage, carrots, garden eggs, and lettuce have substantial metal transfer factors suitable for phytoremediation of polluted soils. Both soil and vegetable samples had higher heavy metal levels. Metal bioaccumulation in plants may occur independently of soil bioavailability.

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Recommendation

Alternative analytical procedures for metals in soil and vegetable samples should be adopted to verify the accumulation levels. Continuous and systematic monitoring programs should be implemented for heavy metals in food items. Thoroughly washing vegetables with clean water before ingestion is essential to diminish metal levels.

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